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^{26}Al measurements with VERA

A. Wallner *, R. Golser, W. Kutschera, A. Priller, P. Steier, H. Vonach, E. Wild

Vienna Environmental Research Accelerator, Institut für Radiumforschung und Kernphysik, Universität Wien, Währinger Straße 17, A-1090 Wien, Austria

Abstract

The Vienna Environmental Research Accelerator (VERA) is a 3-MV Pelletron tandem mass spectrometer system. Since July 1996, extensive tests with ^{26}Al detection were performed. Systematic investigations of reproducibility, transmission, overall efficiency etc. are necessary for a new facility such as VERA in order to come up with reliable results. To this end several different ^{26}Al standards with an ^{26}Al/^{27}Al isotopic ratio between 5×10^{-10} and 1×10^{-12} were used. The results of these investigations revealed no systematic deviation beyond counting statistics. In order to determine the cross section for the ^{27}Al(n,2n)^{26}Al reaction Al-metal samples with ^{26}Al produced from neutron irradiation were measured and compared with ^{26}Al standards. © 1998 Elsevier Science B.V.

Keywords: AMS; ^{26}Al; (n,2n) reaction; Fusion plasma temperature; $^{26}Al_2O_3$ standard

1. Introduction

Vienna Environmental Research Accelerator (VERA) is a dedicated accelerator mass spectrometry (AMS) facility based on a 3-MV Pelletron tandem accelerator [1,2] built by National Electrostatic Corporation (NEC, Wisconsin, USA). On March 1996 the acceptance tests were passed [2]. VERA is a fully computer-controlled facility which allows for unattended (overnight) operation. So far the facility has been mainly used for ^{14}C measurements [3–5], with ^{26}Al as an additional major program.

^{26}Al ($T_{1/2} = 7.2 \times 10^5$ yr) is one of the important radionuclides generated by cosmic ray interaction with argon in the Earth's atmosphere and with silicon in rocks. Applications lie therefore in geophysical studies and in samples originating from extraterrestrial material (meteorites), but also in biomedical research and nuclear physics.

The production of the long-lived radionuclide ^{26}Al through the ^{27}Al(n,2n)^{26}Al reaction is of considerable interest to the fusion reactor program. The threshold of this reaction ($E_{th} = 13.54$ MeV) falls within the spread of energy of the neutrons generated by a deuterium–tritium plasma and was discussed as a possible means to measure the plasma temperature [6]. A prerequisite for this application is the accurate knowledge of the excitation function of the ^{27}Al(n,2n)^{26}Al reaction near threshold. Since data from the literature are insuf-

* Corresponding author. Tel.: +43 140 480 712; fax: +43 140 76 200; e-mail: wallner@pap.univie.ac.at.

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ficient for this purpose, a new program was initiated. First, Al foils were irradiated with 14-MeV neutrons under various angles from the T(d,n)^{4}He reaction in order to obtain ^{26}Al/^{27}Al isotopic ratios from 5×10^{-12} down to background level [7]. For the ^{26}Al/^{27}Al ratio measurements at VERA, several Al standards with well-known ^{26}Al/^{27}Al ratios were investigated with regard to their nominal value, beam current behavior, stability of the AMS system etc. For the cross section measurement, the ^{26}Al/^{27}Al ratios of the neutron-irradiated samples were then measured relative to those of the standard materials.

2. Experimental procedure

For the production of Al^- ions a Cs-beam sputter source (MC SNICS) was used containing a 40-sample target wheel made of Cu. Using a negative ion source, one overcomes the problem of interference of the stable isobar ^{26}Mg with the ^{26}Al detection, since Mg does not form stable negative ions. So far we have used Al metal and Al_2O_3. The material was hammered into sample holders fabricated from copper rod with a hole of 1 mm in diameter. The oxide was mixed with Cu as a conducting powder (roughly 1:1), whereas the metal samples suitably manufactured from pure Al foils (99.999%) were directly pressed into the sample holders. To accelerate the growth of the $^{27}Al^-$ current, the samples were recessed by about 0.3 mm from the holder surface. The amount of Al per sample ranged from 5 mg (for Al_2O_3) to about 10 mg (for Al metal).

Negative ions extracted from the source are preaccelerated to about 70 keV, and pass an electrostatic analyzer for energy selection. This is followed by a high resolution 90° injector magnet for a first mass analysis. The magnet chamber is electrically insulated and can be biased with different voltages. At a fixed magnetic field, this allows for injection of different isotopes (^{26}Al, ^{27}Al) in a short time sequence. The ions are injected into the tandem which is operated at a voltage of 2.7 MV. At the terminal, stripping in Ar gas leads to positively charged ions; molecules are dissociated. A high energy 90° analyzing magnet is set to select the most probable charge state (3^+) of the nuclide of interest. Moveable offset Faraday cups positioned at the exits of both 90° magnets measure the ion current of stable ^{27}Al ions. For $^{26}Al^{3+}$ detection, the ions pass through a Wien ($E \times B$) filter and are finally counted in a Si detector. Ions with the same magnetic rigidity as the ^{26}Al ions passing even the Wien filter are distinguished from ^{26}Al by their energy measured in this detector. No interfering isotopes with mass 26 are observed.

In contrast to ^{14}C measurements [2,4], a fast sequential isotope injection cannot be used for the ^{26}Al/^{27}Al ratio measurement. When measuring ^{27}Al in the off-set Farady cup after the analyzing magnet, we found a huge amount of background particles from ^{27}Al in the silicon detector. This is due to the low-energy tailing of the intense ^{27}Al beam and due to the smaller relative mass difference between adjacent isotopes compared to ^{14}C.

To overcome this problem a slow pulsing mode was chosen. Bouncing the bias voltage applied to the magnet chamber for 10 s allows the measurement of the ion currents ($^{27}Al^-$ and $^{27}Al^{3+}$) with the offset multi-Faraday cups. During this procedure the silicon detector is shielded with inserted Faraday cups. While mass 26 is injected, ^{26}Al is counted in the detector and simultaneously the $^{27}Al^-$current is measured at the low energy side. The duration of this mode was set to 100 s. This procedure (sub-run) is repeated several times for each sample. Corresponding to the number of sub-runs selected, one run lasted between 15 and 30 min. Overall, about 4–8 runs on an individual sample were performed depending on the ^{26}Al/^{27}Al ratio of the selected sample. Spectra obtained with the Si detector are shown in Fig. 1. Four different Al metal samples irradiated with neutrons of an energy between 13.4 and 14.8 MeV result in isotopic ratios ranging over three orders of magnitude. The spectrum with no ^{26}Al count registered originates from an Al sample irradiated with neutrons of an energy below threshold. The additional peaks corresponding to the detection of ^{27}Al and ^{25}Mg ions are well seperated. Due to radiation damage a few weeks of operation leads to degradation of the detector resolution, and therefore the discrimination becomes more problematic. A fully automatized determination of the ^{26}Al/^{27}Al is deli-

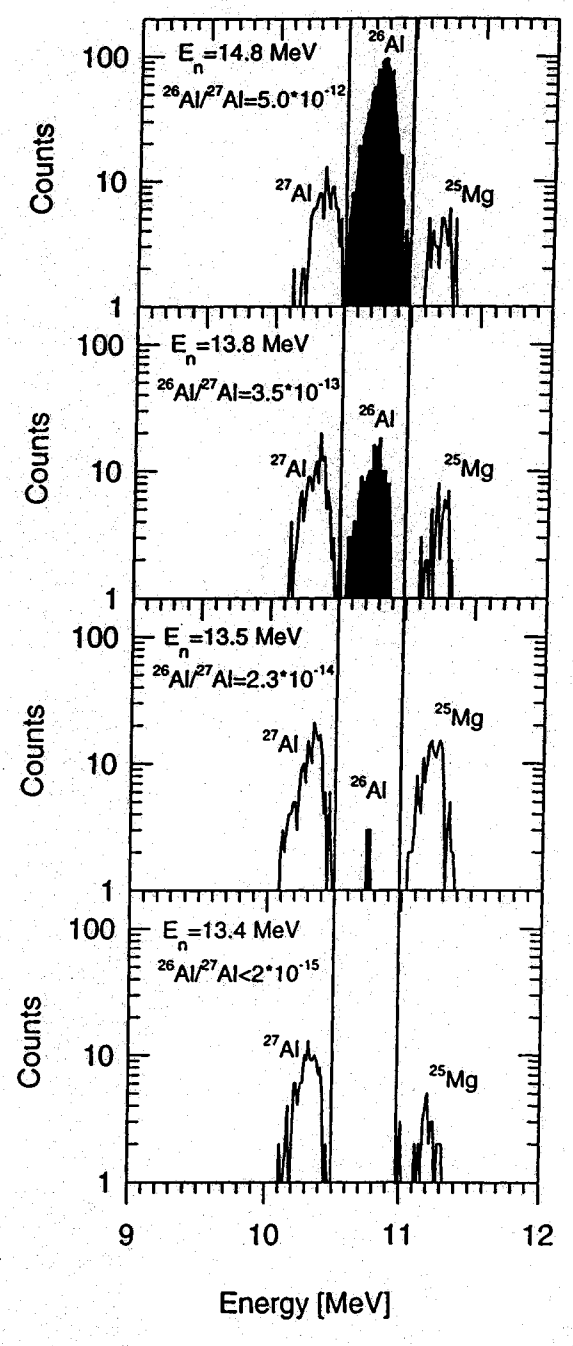

Fig. 1. Energy spectra for ^{26}Al detection measured in the Si detector. The Al metal samples were irradiated with neutrons of different energy generated via the T(d,n)^{4}He reaction under various angles.

cate because of the amount of background particles registered at the detector. This background is much higher for the first few hundred seconds, and then settles to acceptable count rates in the detector system but still can be different for the individual samples.

The total negative-ion current extracted from the ion source reached about 30 μA for Al metal and 55 μA for Al_2O_3. $^{27}Al^-$ currents after the injection magnet were in the range of 100–350 nA. At 2.7 MV terminal voltage and with Ar stripping $^{27}Al^{3+}$ electrical currents up to 500 nA were measured after the high-energy analyzing magnet. The currents are somewhat lower for Al metal samples compared with the Al oxide samples. The lifetime of a typical sample is several hours. The $^{27}Al^{3+}/^{27}Al^-$ transmission calculated from the current measured at the off-set Faraday cups of the analyzing and the injection magnet reached values up to 44%.

3. Results

Several different ^{26}Al standards covering an isotopic ratio between 5×10^{-10} and 1×10^{-12} were available for systematic investigations. Reproducibility, transmission and overall efficiency were investigated.

Fig. 2 shows measurements on three Al oxide standards, which were kindly supplied by Stephan Vogt from Prime Lab at Purdue University. Different symbols indicate samples of the same standard material positioned at different places on the target wheel. These results were obtained over a period of several days. The mean value is shown by the solid line. The standard deviation (dashed line) for the Al standard with 1.62×10^{-11} nominal value is equivalent to 0.56%, whereas from counting statistics (54 000 counts total) 0.43% is expected. For the other standards these values amount to 0.74% (0.84% expected) and 0.86% (1.1% expected). Therefore no systematic deviation can be deduced from these runs.

Measurements of unknown $^{26}Al/^{27}Al$ ratios were compared with Al standards of well-known ratios. These standards act therefore as check for the long-term machine stability and they deliver the absolute scaling factor for the Al ratios. The Al standards used were provided as Al oxides, whereas the unknown (irradiated) samples for the study of the $^{27}Al(n,2n)^{26}Al$ reaction were pure metals. It is not evident that isotope ratios from Al_2O_3 samples behave in the same way as those

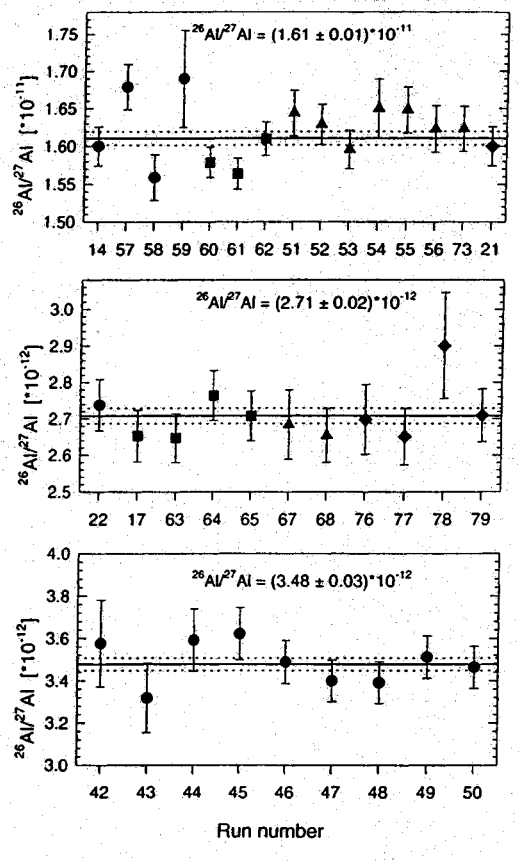

Fig. 2. Absolute $^{26}Al/^{27}Al$ ratios for 3 different Al standards. Different symbols indicate samples of the same material but positioned at different places on the target wheel. The nominal values of this standards supplied by Stephan Vogt from Purdue University (privat comm.) amount to $(1.62 \pm 0.06) \times 10^{-11}$, $(2.72 \pm 0.08) \times 10^{-12}$ and $(3.75 \pm 0.05) \times 10^{-12}$, respectively.

from metal samples. Fractionation effects from the ion production process and a different beam quality on the low energy side may lead to changes in the $^{26}Al/^{27}Al$ ratio measurements. We therefore converted some Al metal samples into Al oxide in order to check for possible differences in the ratio measurements. Fig. 3 shows the ratio obtained from three samples. The error bars correspond to the statistical uncertainty of the individual measurement. The solid line gives the mean value for a specific sample, the dashed line shows the standard deviation of the mean value. As seen from the figure both the metal and the two converted Al_2O_3 samples deliver the same isotopic ratio.

The background is checked with Al blanks, produced from both Al metal (non-irradiated) and Al oxide samples. Only very few counts are registered for blank measurements. This results

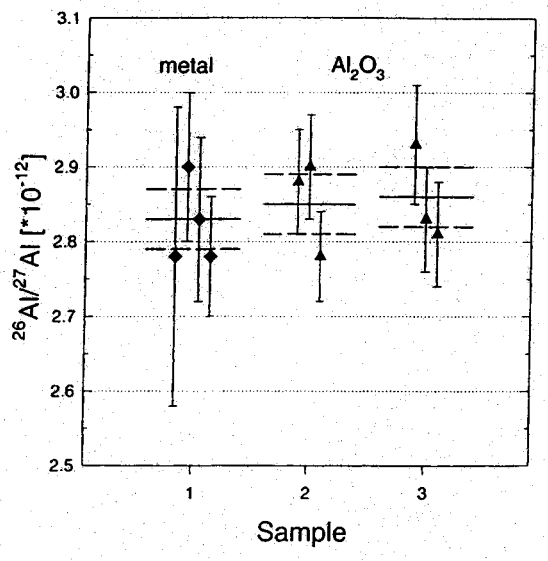

Fig. 3. $^{26}Al/^{27}Al$ ratios for Al samples irradiated with neutrons of the same energy. Sample 2 and 3 were originally metal samples which were converted to Al oxide.

in an isotopic ratio of a few times 10^{-15}. For the cross section measurements the 40-sample target wheel was loaded with 7-8 standards and about the same number of blanks, the remainder were samples with unknown ratios.

First results for the $^{27}Al(n,2n)^{26}Al$ excitation function measurements with VERA are shown in Fig. 4. The solid circles are data points deduced from Al metal samples irradiated with neutrons in Vienna and St. Petersburg [7]. A least-square fit to

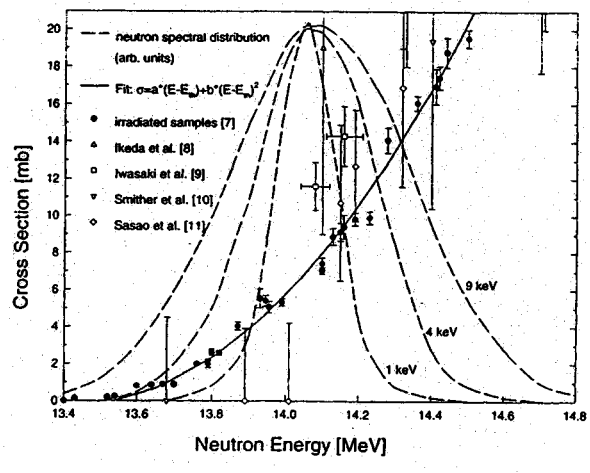

Fig. 4. Comparison of present and previous data for the $^{27}Al(n,2n)^{26}Al$ excitation function at the threshold region from samples irradiated with 14-MeV neutrons. The neutron spectral distribution in a DT-plasma for different temperatures (1, 4 and 9 keV) is also shown.

this data is indicated by the solid line. The background level of the AMS measurements (upper level: 7×10^{-15}) allows for cross section measurements down to 0.07 mb. A comparison with the previously measured cross sections [8–11] clearly shows that our results represent a substantial improvement near threshold. The neutron spectral distribution (in arbitrary units) for three different DT-plasma temperatures is also plotted in Fig. 4 (dashed lines). The centroid remains nearly fixed, but the width of the distribution changes with temperature. A nonlinear increase of the excitation function with neutron energy therefore leads to different production rates of ^{26}Al for different plasma temperatures. Some corrections to the present data are still pending, such as the finite width of the neutron energy distribution due to the irradiation geometry. Presently, the uncertainty of the neutron energy is believed to be smaller than 50 keV, but may be improved. Therefore the data have to be considered preliminary. Still, they already indicate that the temperature sensitivity of the ^{27}Al(n,2n)^{26}Al reaction can be investigated at the level necessary to verify the validity of the original proposal [6].

4. Conclusion

Although VERA is mainly used for ^{14}C measurements, extensive tests with ^{26}Al were performed. Thereby VERA has achieved a status where accurate ^{26}Al/^{27}Al ratio measurements can be performed, with lower limits around 10^{-15}. With this system precise knowledge of the ^{27}Al(n,2n)^{26}Al excitation function and data much closer to threshold than in previous measurements were obtained.

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